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ROCK MASS CHARACTERIZATION AROUND THE CROWN PILLAR AT SELBAIE MINE, QUEBEC

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by

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ABSTRACT

Based on results obtained from a detailed engineering geological survey and application of the CSIR Geomechanics Classification and the NGI Tunnelling Quality Index, the rock mass around the crown pillar at Selbaie Mine has been characterized. The suggested overall assessment of the rock mass strength was 'Fair to Good' for the hanging wall and 'Fair' for the footwall/orebody; the orebody in the south section is relatively weaker, or 'Poor', when compared to the hanging wall and footwall strata. The rock mass characteristics of the weakness zones were indicated as 'Very Poor' to 'Extremely Poor'.

In a relative comparison of rock mass quality, the orebody exhibits the lowest strength; this suggests that more roof support is required in the orebody than in the footwall and hanging wall.

For temporary mine openings in the orebody, the maximum unsupported excavation span is thought to be in the range between 10.5 to 12 m.

The applied classification systems, using sufficient geological data, provide an in situ rating of the rock mass. The results could be a useful guide for mining design, prediction of stability conditions, and the estimation of operational requirements for ground support. However, for production openings or multiple mining excavations, additional parameters, including sequence of mining, effect of blasting, and influence of persistent discontinuities on rock exposures in conjunction with refined rock mass classification will be essential.

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ÉTABLISSEMENT DES CARACTÉRISTIQUES DU MASSIF ROCHEUX AUTOUR DU STOT DE LA MINE SELBAIE, AU QUÉBEC

par

B. Arjang*

RÉSUMÉ

Les résultats d'études géotechniques détaillées et l'application de la classification géomécanique (CSIR) et du système-Q (Indice de qualité du creusement de galeries NGI) ont permis d'établir les caractéristiques du massif rocheux qui entoure le stot de la mine Selbaie. Selon l'évaluation, la résistance du massif rocheux varie de «passable à bonne» dans le toit et est «passable» dans le mur, la section sud du gisement étant relativement plus faible que les strates du toit et du mur. Les zones les moins résistantes ont été classées comme étant d'une résistance «très faible» et «extrêmement faible».

Selon une comparaison relative de la qualité du massif rocheux, c'est le gisement qui a la plus faible résistance. Il faudrait donc assurer un meilleur soutènement au plafond du gisement qu'au mur et au toit.

Pour ce qui est des ouvertures temporaires, on peut penser à pratiquer des galeries sans soutènement d'une longueur maximale de 10,5 à 12 m.

À l'aide de données géologiques suffisantes, les systèmes de classification utilisés permettent d'évaluer sur place le massif rocheux. Les résultats pourraient être utiles pour choisir les méthodes d'extraction minière, prévoir les conditions de stabilité et évaluer des besoins opérationnels en matière de soutènement. Toutefois, lorsqu'il s'agit d'exploitation par galeries multiples ou de galeries de production, il est essentiel de tenir compte d'autres paramètres tels que la séquence d'exploitation, l'effet du sautage et l'influence de discontinuités permanentes sur les affleurements rocheux, et d'utiliser une classification plus détaillée du massif rocheux.

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INTRODUCTION

As part of CANMET's rock mass characterization project, a detailed structural survey of underground exposures was conducted around the near-surface crown pillar at the Selbaie Mine, on the 55, 60 and 70 m levels. These levels were within 10 to 25 m below the rock surface (1). In this engineering geological investigation about 725 structural discontinuities were measured along scanlines. The data on orientation, spacing, trace length, and the observable surface characteristics of the discontinuities were analyzed.

Based on these results and additional data, two classification systems, the Q-system (NGI Tunnelling Quality Index) and the Geomechanics Classifcation (CSIR) have been applied to obtain an overall assessment of the quality of the rock mass around the crown pillar.

ENGINEERING GEOLOGICAL BACKGROUND

The Selbaie Mine, an underground hard rock mine, is located about 95 km west of Matagami in Northwest Quebec. This base metal deposit comprises various lenticular orebodies which are contained in a dacitic rock. The ore zone has a general N-S strike extending about 500 m, and a dip of 40-50° east, with a vertical depth exceeding 180 m below surface. The orebody is covered by up to 50 m of glacial till and sand.

The results of previous engineering geological investigations are summarized and shown in Table 1. The most prominent structural features are the three discontinuity sets and the main fault or fault zone as shown in Fig. 1 and 2.

The observable surface characteristics of discontinuities indicate various degrees of alteration, surface staining or infilling. The weakness planes are rough to very rough irregular undulating structures with apertures

Table 1 - Structural features and discontinuity surface characteristics

Geological Location		Discontinuities	Mean Spacing (m)	Weathering %		Infilling %			Water Occurrence %		
				Unweathered	Weathered	Free	Stained	Infilling	Dry	Dry, past Water Flow	Damp, Continuous Water Flow
H/W		2 joint sets	0.71	14	76	40	26	34	34	33	33
O/B	N*	3 joint sets	0.72	8	92	33	49	18	9	52	39
	S*	3 joint sets + random	0.59	-	100	23	44	33			
F/W	N	2 joint sets + random	0.76	17	83	30	40	30	24	57	19
	S	3 joint sets	0.76	9	91	12	49	39			

* North section (N): 3 + 50N to 5 + 00N (60 level); South section (S): 3 + 50N to 2 + 00N (55, 70 levels). The structural regions, North and South section, were used throughout this report.

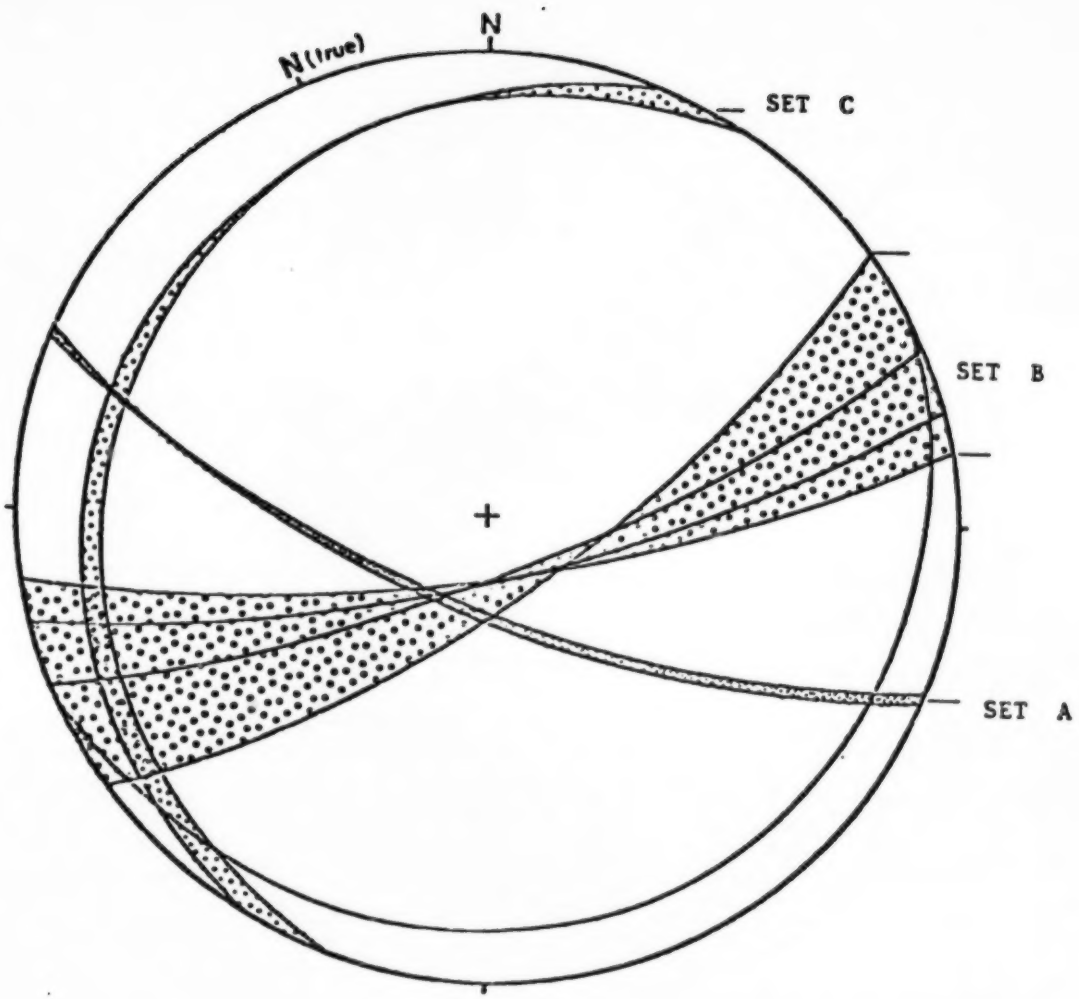

Fig. 1 - Orientation of prominent structural features in the footwall strata.

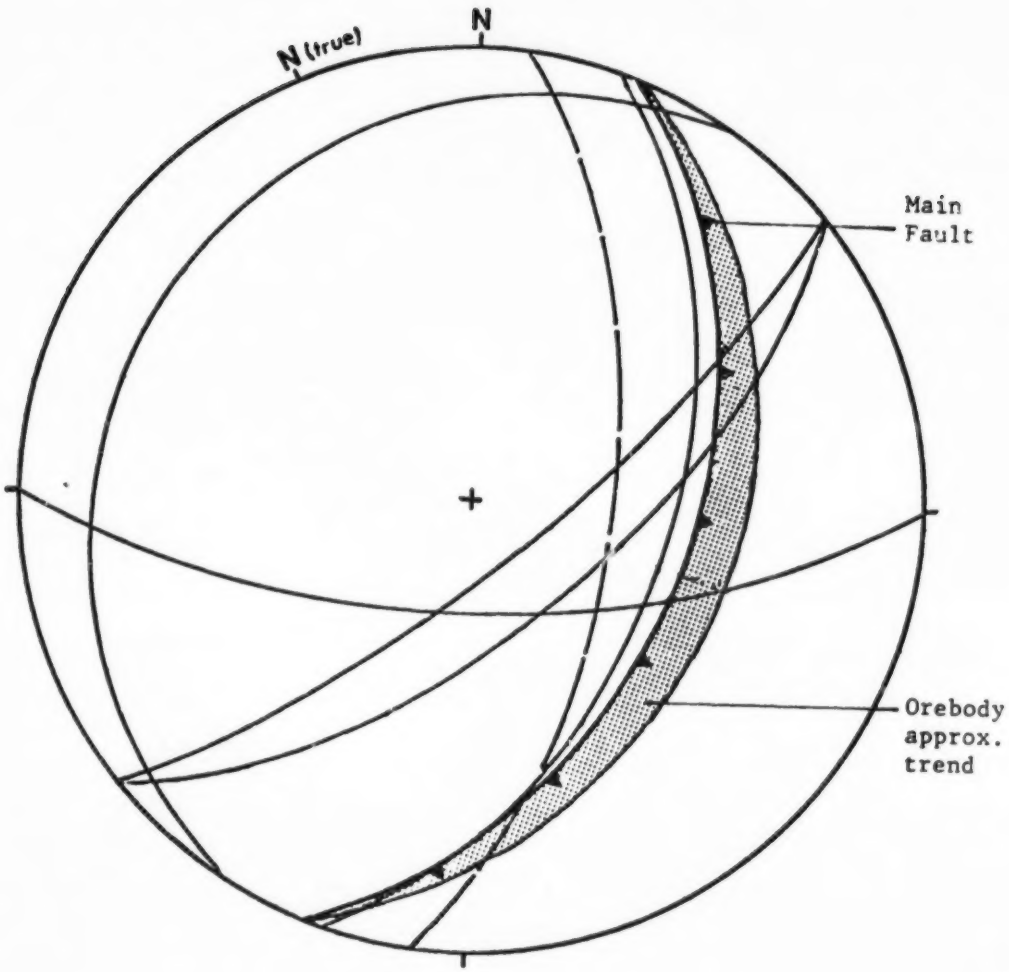

Fig. 2 - Orientation of prominent structural features in the orebody and hanging wall strata.

ranging in the order of up to a few millimeters.

Because of the structural features and the observable surface characteristics, particularly the effect of weathering, infilling and water inflow, the investigation site was divided into two structural regions: North and South sections along the strike of the orebody.

ROCK QUALITY DESIGNATION (RQD) AND DISCONTINUITY SPACING

In most of the existing rock mass classification systems the RQD value represents a common parameter which provides an objective comparison between different rock qualities. RQD is based upon core recovery from drill holes which, in turn, is based directly on the number of fractures observed in the rock core (2).

Experience has shown that a complex set of parameters exists, which could lead to unrepresentative RQD values of rock mass. Furthermore, if the discontinuity spacing is obtained from core, there is a possibility that additional fractures may have been introduced by the sampling process since intact core can be snapped during drilling. This, together with the phenomenon of discing, if a high field stress exists, could lead not only to an artificially lowered RQD, but also to an artificially imposed discontinuity spacing. In addition, poor drilling equipment and technique, or not specified core size (e.g., less than 50 mm), handling of core material, or poor supervision of drilling are of concern. In fact, different RQD values measured over a few metres length of the borehole can be a reflection of the random spacing of the discontinuities.

The major limitations in the applicability of the Rock Quality Designation System are not only an inability to assess the spacing from a single set of borehole cores, but also a disregarding of the influence of discontinuity orientation, surface asperities, continuity, and presence of infilling material

(because it is washed out by drilling procedures). The conventional RQD is also insensitive to variations in rock quality when the mean discontinuity spacing exceeds 0.3 m, which occurred the investigation site.

In this regard, underground openings have certain advantages over drill holes; because by surveying of refined discontinuity characteristics more realistic values of spacing may be obtained. In this work, therefore, an attempt was made to determine RQD values from surveying of discontinuity spacings along scanlines on rock exposures (3).

In this procedure the possible distribution of discontinuity spacing (evenly-random-cluster distribution) along a scanline is considered. This only applies if the discontinuity spacing values follow a negative exponential distribution. This appeared to be appropriate in the field investigations at the Selbaie Mine. For evaluation purposes a certain scanline length is necessary for a reasonable estimate of discontinuity frequency and a sufficient number of observations in structural mapping should be considered.

Utilizing the negative exponential distribution, a relation between the theoretical Rock Quality Designation (RQD*) and mean discontinuity spacing per metre (λ) is established; under the condition that the percentage of scanline consisting of intact rock lengths is set up at 0.1 m:

$$RQD^* = 100\ e^{-0.1\lambda}(0.1\lambda + 1)$$

Table 1 summarizes values of RQD for the rock mass, calculated from measurements in the hanging wall, orebody and footwall. These values were used for rock mass characterization purposes in both classification schemes.

ROCK MASS CHARACTERIZATION

The successful application of rock mass characterization for engineering projects depends upon the purpose of the work and also the use of

Table 2 - Estimated RQD values from discontinuities spacing

Location		Scanline (m)	No. of Observations	Mean Spacing (m)	λ	RQD %
H/W		30	42	0.71	1.40	99.1
O/B	N	37	51	0.72	1.37	99.1
	S	143	85	0.59	1.68	98.7
F/W	N	100	134	0.74	1.34	99.1
	S	208	273	0.76	1.31	99.2

a system that is suited to particular conditions. In regard to underground mining excavations, the Q-system (NGI Tunnelling Quality Index) and the Geomechanics Classification (CSIR) have been found to be the most promising (4,5,6). Both systems clearly define their parameters which are measurable in the field investigation and they also include sufficient data to provide a realistic assessment of the factors which influence the stability of underground excavations.

Based on results obtained by an engineering geological survey, underground observations (Tables 1 and 2), and available data in both classification systems, the rock around the crown pillar has been characterized as follows.

Q-SYSTEM (NGI TUNNELLING QUALITY INDEX)

The Q-system of rock mass classification is based on a numerical assessment of the rock mass quality (Q), using six different parameters. The parameters consist of the RQD, the number of joint sets (Jn), the joint roughness (Jr), the degree of alteration (Ja), the water inflow (Jw), and the stress condition or stress reduction factor (SRF). These are found to be crude measures of: relative block size (RQD/Jn), interblock shear strength (Jr/Ja) and active stress (Jw/SRF). The numerical value of overall rock mass quality is defined by:

$$Q = (RQD/Jn)\cdot(Jr/Ja)\cdot(Jw/SRF)$$

where the possible Q values range approximately from 0.001 to 1000.

The values of different parameters corresponding to the Q-system and defining the rock mass characteristics in the investigation site are given in Table 3.

According to the Q values, the overall rock mass quality would be 'Good' in the hanging wall, 'Fair' in the footwall and orebody. In the South

Table 3 - Rock mass parameters and Q-values for H/W, O/B and F/W around the crown pillar in Q-system.

Location	Parameter*:	RQD %	Jn	Jr	Ja	Jw	SRF	Q
H/W		99.1	4	3	2	1.0	2.5	14.86
O/B	N	99.1	9	3	2	0.66	2.5	4.36
	S	98.7	12	3	2	0.66	2.5	3.25
F/W	N	99.1	6	3	2	0.66	2.5	6.54
	S	99.2	9	3	2	0.66	2.5	4.36
Fault zone (on F/W, O/B contact)		25	20	1	5	0.66	2.5	0.06

* Description and ratings of parameters used for calculation of the Q-values:

ROD = 25% estimated value for the fault zone

Jn = 4, two joint sets

Jn = 6, two joint sets plus random

Jn = 9, three joint sets

Jn = 12, three joint sets plus random

Jr = 3, rough or irregular, undulating

Ja = 2, slightly weathered joint walls

Ja = 5, zones or bands of silty or sandy clay, small clay fraction (non-softening)

Jw = 1.0, dry excavation or minor inflow

Jw = 0.66, medium inflow or pressure, occasional outwash of joint fillings

SRF = 2.5, low stress, near surface

SRF = 2.5, single weakness zones containing clay, or chemically disintegrated rock (depth of excavation >50 m)

Note: Stress reduction factor was assumed to be 2.5 for low stress, but this does not correspond to estimated values of σ_c and σ_1 (unconfined compressive strength and major principal stress) suggested in the classification scheme. However, the low stress (SRF = 2.5) appears to be more appropriate in the investigation site rather than medium stress (SRF = 1.0) where the estimated values σ_c and σ_1 correspond to the suggested values in this classification.

section of the orebody quality would be characterized as 'Poor', and, in the fault zone, as 'Extremely Poor'.

The maximum unsupported excavation span is defined in the Q-system as:

$$\text{Excavation span} = De \times ESR$$

where, De = equivalent dimension,

ESR = excavation support ratio.

For an orebody with Q-values of 4.36 to 3.25 the maximum equivalent dimension according to Fig. 3 amounts to 4 and 3.5. When the excavation support ratio is taken as 3 (from suggested ESR = 3-5 for temporary mine openings) the maximum unsupported excavation span, which can be considered for the excavations in the orebody (such as stopes) is 12 to 10.5 m.

The Q-system assumed a relationship between the stand-up time and the rock mass quality (Q) as a function of different unsupported excavation spans. Based on this relationship, a preliminary stand-up time for single openings, such as drifts, can be predicted as:

Location	Q-Values	Class	Max. Unsupported Span (m)	Stand-Up Time (Assumed Range)
H/W	14.85	Good	10	10-50 years
O/B	3.25/4.36	Fair/Poor	10	4 mth-1 yr/8 mth-3 yr
F/W	4.36/6.54	Fair	10	8 mth-3 yr/1-6 yr

A relationship between roof support pressure and rock mass quality as a function of joint set number (Jn) and joint roughness number (Jr) is defined as:

$$P_{roof} = \frac{2\ Jn^{1/2}(Q)^{-1/3}}{3\ Jr}$$

Utilizing this empirical equation, permanent roof support pressure can be

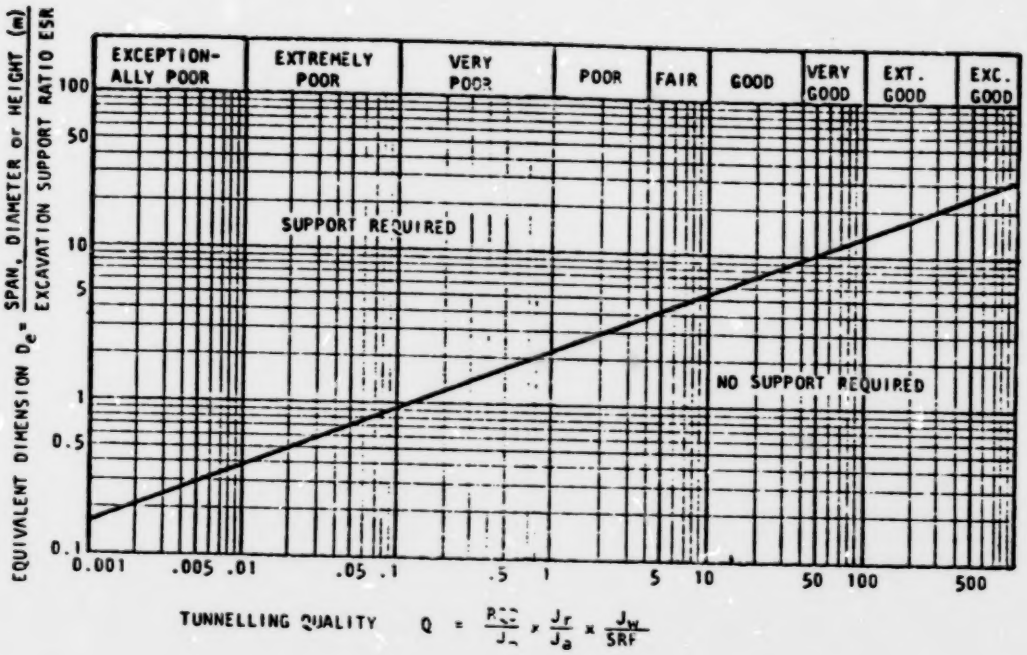

Fig. 3 - Relationship between the maximum equivalent dimension D_e of an unsupported underground excavation and the NGI Tunnelling Quality Index Q (4,6).

established as follows:

Location		Q-Index	Jn	Jr	$\frac{P}{(kg/cm^2)}$	Comments
H/W		14.86	4	3	0.27	For the H/W with two joint sets the equation: $P_{roof} = (\frac{2.0}{Jr})Q^{-1/3}$ is applicable.
O/B	N	4.36	9	3	0.40	
	S	3.25	12	3	0.51	
F/W	N	6.54	6	3	0.29	
	S	4.36	9	3	0.40	

GEOMECHANICS CLASSIFICATION (CSIR)

The geomechanics classification results in a rating for the rock mass, which is obtained by assessing the five geological properties that affect strength: the RQD, the intact rock strength, the joint spacing, the joint condition and groundwater. To obtain a final rock mass rating an adjustment of the in situ (basic) rating is recommended. This depends upon discontinuity orientation, weathering, field and induced stresses, stress changes due to mining, and the effects of blasting (7). The proposed adjustments are made by modifying the basic value of a particular parameter.

Based on available data, the in situ (basic) and final (adjusted) rock mass ratings are given in Table 4.

At the investigation site, the condition of discontinuities is affected by various degrees of weathering, either the discontinuity surfaces and/or the infilling. In addition, RQD and the intact rock strength values are decreased by alteration processes. Therefore, regarding the overall geological condition an adjustment of weathering (75-82% for H/W, O/B, F/W and 60% for fault zone) appeared to be appropriate. Adjustments for the effect of blasting (94%

Table 4 - Rock mass parameters and ratings for H/W, O/B and F/W around the crown pillar in Geomechanics Classification

Location		Parameter						
		Rock Strength (MPa)	RQD %	Joint Spacing (m)	Joint Condition	Ground-Water	In Situ Rating	Final Rating
H/W		50-100	99.1	0.71	+	x		
	Rating	7(12)	20	20	6	10	63(68)	48(52)
O/B	N	50-100	99.1	0.72	+	▲		
	Rating	7(12)	20	20	6	7	60(65)	45(49)
	S	50-100	98.7	0.59	+	*		
	Rating	7(12)	20	20	6	4	57(62)	40(44)
F/W	N	50-100	99.1	0.74	+	▲		
	Rating	7(12)	20	20	6	7	60(65)	46(50)
	S	50-100	99.2	0.76	+	*		
	Rating	7(12)	20	20	6	4	57(62)	43(47)
Fault zone		3-100	<25	-	■	*		
	Rating	0	3	20	0	4	28	∿16

Intact rock strength values are based on field estimations and represent an approximate uniaxial compressive strength. The overestimated ratings of rock strength and the corresponding rock mass ratings are given in brackets.

▲ moist

* water under moderate pressure

x completely dry

+ continuous joints, open 1-5 mm

■ soft gouge >3 mm thick, continuous joint.

proposed for good conventional blasting) were also made to obtain the final estimation of rock mass rating. Because of the low field, or induced stresses, (<25 MPa) on a sub-surface mining excavation their influence on the condition of discontinuities is not expected to be significant, therefore no adjustments were taken into consideration.

Based on final (adjusted) ratings, as shown in Table 4, the rock mass would be characterized as 'Fair' in the H/W, F/W and 'Fair to Poor' in the O/B strata, which suggests the following properties and practical meaning of rock mass classes:

	'Fair Rock'	'Poor Rock'
Average stand-up time:	1 wk for 3 m span	5 h for 1.5 m span
Rock mass cohesion:	150-200 KPa	100-150 KPa
Rock mass friction angle:	35°-40°	30°-35°

The results of the rock mass characterization obtained from both classification systems are compared and given in Table 5.

DISCUSSION

Rock mass characterization is a useful means of quantifying the properties of a rock mass for the purpose of predicting stable spans and support requirements for excavations. The Q-system and Geomechanics classification, basically developed for civil engineering projects (single openings), requires further assessment for useful application in underground mine openings. One of the basic functions of rock mass classification is to be able to estimate ground support requirements, but these estimates are mainly based on experience and need some improvement.

A comparison of the two classification systems indicates a major discrepancy in predicting stand-up time as a function of rock mass quality and

Table 5 - Comparison of rock mass characteristics in Q-system and Geomechanics classification

Location		Q-System		Geomechanics Classification		RMR	Comments
		Q-Index	R.M. Class	Rating	R.M. Class		
H/W		14.85	'Good'	48(52)*	'Fair'	54	Equation: RMR = 9 Log Q + 44 defined the relationship between the two systems for correlation purposes.
O/B	N	4.36	'Fair'	45(49)	'Fair'	49	
	S	3.25	'Poor'	40(44)	'Poor'	48	
F/W	N	6.54	'Fair'	46(50)	'Fair'	51	
	S	4.36	'Fair'	43(47)	'Fair'	49	
Fault zone		0.06	'Extremely poor'	16	'Very poor'	33	

* Over-estimated rock mass ratings are given in brackets.

unsupported span width. The preliminary attempt to predict the stand-up time appears to be either too conservative (or over-estimated). These can only be applied with some provisos for mining situations.

The Q-system incorporates the effects of discontinuity characteristics in greater detail and provides more refined and consistent rock mass ratings. However, by application of this classification system sufficient information based on field data is essential for specific objectives, such as support requirements and prediction of stability conditions around production openings. No account is taken of the orientation of continuous structures, i.e., favourably or unfavourably oriented to exposure surface, and of the influence of blasting on support which can be incorporated in the ESR factor (Excavation Support Ratio).

If the negative exponential distribution of discontinuity spacing is accepted as valid, the RQD can be calculated from the mean number of discontinuities per metre. It was found, however, that a sufficient number of measurements of all existing fractures in a required scanline length is essential to obtain RQD values with a reasonable precision. At the investigation site the RQD values obtained were relatively high indicating some deviation from the true discontinuity distribution patterns. The disagreement with actual RQD, which appears to be lower for the encountered rock, possibly resulted from the small number of measurements, since the existing small scale fractures were not measured.

CONCLUSIONS

Reasonable engineering solutions to problems of underground opening stability can be obtained using sufficient geological data and a rock mass classification system which is suited to particular conditions. The results of the rock mass characterization can provide a useful guide for mining design and estimation of operational requirements for ground support.

Considering the fact that there are some differences of terminology in description of rock mass categories and their boundaries in the applied classification systems, the results obtained were reasonably consistent. Based on available data, the rock mass around the crown pillar at the Selbaie Mine can be characterized as 'Fair to Good' in the hanging wall, and 'Fair' in the footwall and the orebody. The orebody strata in the south section are relatively weaker, or 'Poor', compared to hanging wall and footwall strata. In the weakness zones 'Very poor' to 'Extremely poor' rock characteristics can be expected.

In a relative comparison of rock mass quality the orebody exhibits the lowest strength; this suggests more roof support is required in the orebody, particularly in the south section, than in the footwall and hanging wall strata.

For temporary mine openings in the orebody, the maximum unsupported excavation span is thought to be in the range of from 10.5 to 12 m.

The results of overall rock mass characterization, obtained from existing excavations (drifts and crosscuts), can be extrapolated, with some provisos, on designed production openings or multiple mining excavations in the crown pillar section. For these objectives some parameters, including the excavation dimensions, sequence of mining, effect of blasting and persistent discontinuities on exposure surfaces in conjunction with more refined rock mass classification would be preferred. The influence of these parameters on the stability of the surrounding rock mass is of particular importance for the application of a rock mass classification in underground mines openings.

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